

A local infrared perspective to deeper ISO surveys

D.M. Alexander¹ and H. Aussel²

¹ International School for Advanced Studies, SISSA, Trieste, Italy

² Osservatorio Astronomico di Padova, Padova, Italy

Abstract. We present new techniques to produce IRAS 12 μm samples of galaxies and stars. We show that previous IRAS 12 μm samples are incompatible for detailed comparison with ISO surveys and review their problems. We provide a stellar infrared diagnostic diagram to distinguish galaxies from stars without using longer wavelength IRAS colour criteria and produce complete 12 μm samples of galaxies and stars. This new technique allows us to estimate the contribution of non-dusty galaxies to the IRAS 12 μm counts and produce a true local mid-infrared extragalactic sample compatible with ISO surveys. We present our initial analysis and results.

1 The importance of the local infrared picture

The recent ISO mission has produced a number of deep mid-infrared extragalactic surveys [1,2,3,4] many of which are presented elsewhere in these proceedings. In order to accurately evaluate the apparent source evolution found in these surveys it is essential to have a stable and exact local infrared picture that is compatible with ISO surveys.

2 Previous work and problems

There have been a number of previous IRAS 12 μm extragalactic samples produced from either the Point Source Catalog, hereafter PSC, or the Faint Source Catalog, hereafter FSC. The FSC was constructed by co-adding the individual PSC scans and is consequently deeper at 12 μm by approximately one mag; the FSC is considered complete to $f_{12} > 0.2$ Jy. Due to the greater depth of the FSC only those samples constructed from it will be considered here [5,6 hereafter RMS and FSXH]. In essence none of these samples are truly compatible with the deeper ISO surveys because they apply longer wavelength IRAS colour selection criteria and do not objectively classify galaxies. Some of these samples additionally suffer from inaccurate source flux estimation, no correction for the overdensity due to large scale structure and inaccurate K-correction. Due to the lack of space here these latter two points are not considered although we refer the interested reader to [6,14] for excellent coverage of these problems.

2.1 The colour selection problem

Selecting objects at 12 μm without colour selection will produce an abundance of stars over galaxies due to the Jeans tail of stellar emission. Without exception every extragalactic 12 μm sample to date has had (the majority of) stars removed by applying longer wavelength IRAS colour criteria. This technique is clearly incompatible with ISO surveys where no colour criterium is applied and will cause a bias towards dusty galaxies. This also enforces that every galaxy must have a longer wavelength flux, producing incompleteness even within the selection boundaries. For example, in RMS the primary selection is $f_{12} > 0.22$ Jy but every galaxy must also have $f_{60} > 0.5f_{12}$ or $f_{100} > f_{12}$. However due to the completeness of FSC ($f_{60} > 0.2$ Jy and $f_{100} > 0.6$ Jy) this sample cannot be complete for $f_{12} < 0.4$ Jy or $f_{12} < 0.6$ Jy respectively.

2.2 The classification problem

To produce accurate extragalactic luminosity functions and understand the galaxy contributions to fainter source counts it is necessary to classify galaxies in an objective way, the most common technique is with optical line ratios [7,8]. To date the only classified 12 μm sample is RMS although their classification was taken from various catalogues which differ in the definition of extragalactic type and completeness. As a comparison to this classification we have obtained line ratios from the literature for 349 of the 483 RMS galaxies with $\delta > 0$ degrees. This gives completenesses of 72%, 78% and 93% for objects $f_{12} > 0.22$, 0.3 and 0.5 Jy respectively. Due to the spectroscopic incompleteness at lower fluxes and the colour selection incompleteness we only consider those of $f_{12} > 0.5$ Jy here, see table 1; our classification follows that of [7,9].

Table 1. Extragalactic classification

	AGN	LINER	HII
RMS	13%	15%	-
AA	16%	24%	60%

All galaxies are found to show $\text{H}\alpha$ emission although for some galaxies $W_{\lambda}(\text{H}\alpha) < 1$ angstrom and they would appear as absorption line objects in lower resolution/signal to noise spectra. Of the HII galaxies, 50% show evidence for significant star formation ($W_{\lambda}(\text{H}\alpha) > 10$ angstroms). RMS classified an object as an AGN if it is present in an AGN catalogue. We find a good agreement in classification for this object class, the principal reason for the construction of the RMS sample. LINERs were classified in the RMS sample if they were present in an AGN catalogue and consequently this sample is thought to be incomplete. We confirm this here. RMS did not classify HII

galaxies although they considered those galaxies not classified as a LINER or AGN, but with high infrared luminosities, to be starburst galaxies and all other objects to be normal galaxies.

2.3 The source flux problem

The FSC detection algorithm has been optimised for unresolved sources therefore fluxes for extended sources need to be calculated from the coaddition of scans (the ADDSCAN technique nowadays accessed via XSCANPI) [10]. However, if a source is unresolved, the flux calculation using this technique leads erroneously to a larger flux than the FSC flux [10]. Whilst FSXH carefully calculate the fluxes of extended and unresolved sources separately, RMS treat all sources as extended and consequently overestimate the fluxes of unresolved galaxies; due to the large beamsize of IRAS a large number of galaxies can be overestimated. The magnitude of this effect can be estimated from ISOCAM observations. Unfortunately only a few observations are available for the lw10 filter (the closest to the IRAS 12 μm band) therefore in order to predict the IRAS 12 μm fluxes we have used observations in the lw2 (6.7 μm) and lw3 (14.3 μm) bands and a spectral decomposition technique similar to that described in [11]. In this simple model the mid-infrared emission is produced by two components: HII regions (using M17 [12]) and photo-dissociation regions (PDR) (using NGC7023 [13]). The ratio of HII to PDR is calculated from the ratio of lw2 to lw3 fluxes, a synthetic spectra is produced and the IRAS 12 μm flux is calculated. This technique will be somewhat imprecise due to the uncertainty of the CAM photometry and the ability of the model to reproduce the galactic spectrum. Overall we estimate an uncertainty of $\sim 20\%$, roughly equal to the worst error in the FSC photometry. In figure 1 we plot our predicted fluxes against the FSC and RMS fluxes divided by the predicted flux (i.e. the relative errors in flux).

Only those galaxies with $z > 2,500 \text{ km s}^{-1}$ have been plotted as they should all be unresolved in the IRAS beam. In general a good agreement between the predicted flux and FSC flux is found leading us to believe that the true fluxes for these objects are close to the FSC flux. Consequently RMS may be overpredicting the source flux for $\sim 50\%$ of their objects. This will have the effect of shifting galaxies from faint flux/luminosity bins to higher bins causing unpredictable effects in the source count and luminosity function determinations.

3 A new IRAS 12 μm sample

Our new IRAS 12 μm sample aims to address these problems and create a local infrared sample that is compatible with ISO surveys. The sample definition is close to that of RMS: sources are taken from the FSC for those objects with $|b| > 25$ degrees, $f_{12} > 0.2 \text{ Jy}$ and a moderate or good quality

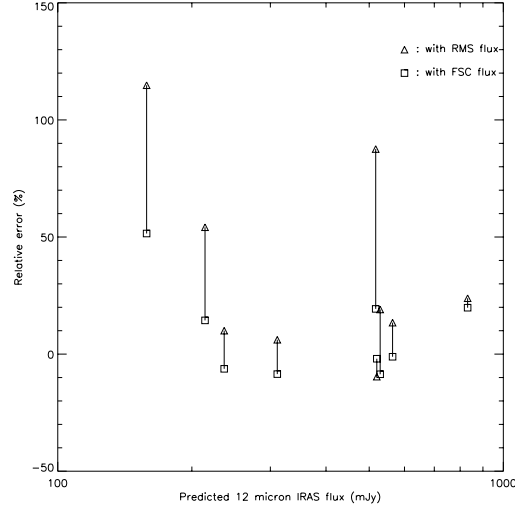


Fig. 1. 12 μ m flux comparison

detection ($S/N > 3$). This selection results in 31002 objects, by comparison the RMS colour selection bias produces ~ 1100 objects.

Our sample provides an interesting complement to the PSC-z extragalactic survey [15] which selects those objects from the PSC with $f_{60} > 0.6$ Jy. As with our sample they do not apply colour selection criteria, stars are identified on Schmidt plates. In terms of the extragalactic objects we would expect many galaxies in common although our sample should have a higher fraction of quasars and early type galaxies.

3.1 The stellar infrared diagnostic correlation

By not applying colour selection to distinguish galaxies from stars we have had to devise an alternative technique. The key assumption in our technique is that stars have, in the majority, predictable properties and therefore with the large and complete optical stellar databases currently available (in particular the Guide Star Catalogue [16], hereafter GSC) it is possible to find the majority of stars in our sample through positional cross correlation. An important factor here is in determining the completeness of an optical stellar catalogue in an infrared sample, requiring an understanding of the general optical and infrared characteristics of stars.

To determine these characteristics for our stars we have used SIMBAD, which provides stellar classifications, and produced a large sample (~ 9000 objects) of classified stars. When cross correlating to optical positions we consider a star correlated if its optical position falls within 5σ of the IRAS position (the mean major and minor error ellipse axes are $16.9''$ and $2.0''$ re-

spectively). The properties of our classified stellar sample are shown in figure 2. We have only plotted those stars for which there are at least 10 objects in a classified class and only a subset of these classes are shown here for clarity. A clear correlation between stellar type and flux ratio is found. The predicted black body colours for the different stellar types follows a straight line passing close to the A1V to K5III points. The interesting deviation observed for stars beyond type M0III is *possibly* due to an increasing amount of stellar absorption in the V band.

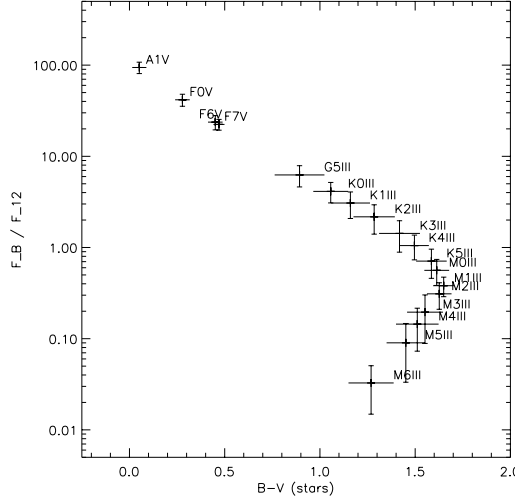


Fig. 2. Stellar infrared diagnostic diagram

These optical-infrared flux correlations provide an essential tool, the ability to predict the IRAS 12 μm flux of a star for a given spectral type or B-V colour. In the cases where we find an IRAS source associated with both a galaxy and a star we will be able to predict the flux from the star and therefore estimate the flux from the galaxy.

3.2 Cross correlating stars

The GSC is considered complete for $6 < V < 15$ mags over the whole sky. Based on our stellar infrared diagnostic correlation this corresponds to a depth of $f_{12} > 0.2$ Jy and therefore any stars earlier than a type M6III in our sample should be in the GSC. However, to accurately cross correlate the positions between the GSC and our sample requires accounting for proper motion. The Schmidt plates for the GSC were taken in 1975 and 1982, by comparison the mean IRAS observation epoch is 1983.5. By analysing a sub-sample of

Hipparcos stars (~ 4000 objects, selected by sky area) we find a mean proper motion of $0.03''\text{yr}^{-1}$, with a one σ maximum of $0.13''\text{yr}^{-1}$ (the maximum in the whole catalogue is $6''\text{yr}^{-1}$). Taking into account the different observation epochs and the mean IRAS error ellipse, virtually all our stars should fall within 5σ of their GSC position.

We initially searched for associations by selecting all objects within $2'$ of the IRAS position ($2'$ corresponds to $\sim 5\sigma$ of the mean positional uncertainty in the major axis direction) although we only consider a star cross-correlated if it falls within 5σ of an IRAS source. From this cross correlation we find that over that 29000 of our IRAS sources are stars. Of these a small ($\sim 0.5\%$), but significant, fraction show a considerable infrared excess ($f_{25} > f_{12}$) and warrant further study.

3.3 Cross correlating galaxies

Our extragalactic cross correlation is performed in a similar manner although the problems associated with correlating galaxies are somewhat different. Proper motion is not a problem although the extended size of galaxies is as the peak mid-infrared position can vary from the peak optical position and therefore some positional uncertainty must be included when trying to correlate an infrared galaxy to an optical source. Although a 5σ positional uncertainty can correspond to $2'$ if the galaxy lies along the major axis of the IRAS error ellipse it can also correspond to just $10''$ if the galaxy lies perpendicular to this direction. Therefore we only consider a galaxy cross correlated if it falls within 10σ of an IRAS source. Due to the often unknown incompleteness of extragalactic catalogues it is not possible to accurately determine the completeness of our sample in extragalactic catalogues and therefore we have simply used the largest (and most appropriate) databases. In the cross correlation presented here we have used the QIGC sample [17], which has just become available in electronic form, NED, SIMBAD and the FSC $25\ \mu\text{m}$ sample [18].

Using these databases we find that over 700 of our sources, not confirmed as stars, fall within our 10σ threshold. From these confirmed galaxies we find ~ 50 are elliptical or S0 systems (not all are active galaxies) and ~ 150 have $f_{12} > f_{25}$ and are most probably PDR dominated galaxies. A number of galaxies have $f_{12} > 2f_{60}$ and would therefore not be picked up by RMS. One of these galaxies is NGC 3115, a nearby bulge dominated galaxy of Hubble type S0. This galaxy is only detected at $12\ \mu\text{m}$, the 25, 60 and $100\ \mu\text{m}$ fluxes are upper limits, although with a V band mag of ~ 8.9 it is bright optical galaxy. In terms of its B-V (1.0) and B/12 (2.5) colours it corresponds to a K0III star. As a comparison we have plotted a sample of our *normal* infrared galaxies, see figure 3.

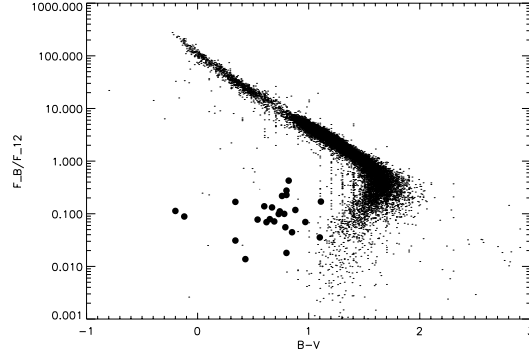


Fig. 3. Stellar and galactic colour plot. All confirmed stars are plotted as dots and a selection of normal infrared galaxies are plotted as filled circles. NGC 3115 is not plotted here but would correspond to the position of a K0III star, see figure 2

3.4 Further improvements

Although our initial cross correlation has been successful we have ~ 500 objects for which we do not have an optical identification. These objects do not have IRAS Cirrus/Confused flags or low $12\ \mu\text{m}$ fluxes although approximately 75% have upper limit $60\ \mu\text{m}$ IRAS fluxes. Visual inspection of a number of these objects with the Digital Sky Survey shows them to be nearby bright stars, suggesting incompleteness in the GSC at bright fluxes. However there is also probably a substantial population of stars not yet accounted for: those with $V > 15$ mags (e.g. M7III and M8III stars), dark molecular clouds and planetary nebulae. We are currently compiling a list of additional stellar objects to cross correlate to our sample to allow us to produce a definitive list of unidentified extragalactic sources.

4 Further work

Our primary aim is to construct complete $12\ \mu\text{m}$ FSC selected samples of galaxies and stars. From this we will create accurate extragalactic source counts and classified luminosity functions with optical slit spectroscopy. As many of our extragalactic objects will be extended we also intend to obtain integrated spectra to provide a classification which is compatible with the distant objects found in ISO surveys where the observed slit spectra will be produced by the majority of the galaxy. With our stellar sample we wish to create a complete list of high galactic latitude stars and sources to help constrain galactic models and provide further diagnostics in distinguishing stars from galaxies in faint surveys (e.g. the Hubble Deep Field [3]). Both our galactic and stellar samples show objects that deviate from the norm (i.e. galaxies with stellar colours and stars with galactic colours) and warrant

further study in their own right.

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